THE RELATIONSHIP BETWEEN WEATHER CONDITIONS AND TRAVEL CHARACTERISTICS IN KOREAN FREEWAYS

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ABSTRACT

Several factors such as accidents, road maintenance, and bad weather contribute to traffic congestion. Among them, weather greatly affects road safety through the increased risk of crashes, as well as the increased exposure to weather-related hazards. It is also known that inclement weather conditions decrease the demand for transport while also decreasing the capacities of freeways. However, it is still unclear exactly how much transport demand and freeway capacity decrease under adverse weather conditions. Moreover, traffic congestion that arises due to bad weather may alter the destinations of travelers or cause them to altogether forego their trips. Although information on trips by origin and destination is required for analyzing transportation planning in urban areas, few studies have examined the relationship between weather conditions and travel patterns.

This work examines changes in expressway travel patterns that arise due to adverse weather conditions and analyzes the effect of weather conditions on the volume of traffic and the travel distance. We compare normal travel patterns with those of rainy days with regard to the travel distance for each type of vehicle. Results show that, as expected, the traffic volume and travel distance decrease in rainy days; the findings also reveal differing travel patterns for weekdays as compared with weekends.

1. INTRODUCTION

Adverse weather conditions such as rain, strong winds or snowfall threaten surface transportation nationwide and negatively impact road safety, mobility, and productivity as well as travel patterns. Bad weather affects road safety through the increased risk of crashes, as well as the increased exposure to weather-related hazards. It is known that inclement weather conditions decrease the demand for transport while also decreasing the capacities of freeways (Goodwin, 2003). If the rate of decrease in freeway capacity is greater than the rate of decrease in the demand for transport, traffic will be congested. It has been noted that 15 percent of congestion occurs due to bad weather conditions (Cambridge Systematics, 2005). However, it is still unclear exactly how much transport demand and freeway capacity decrease under adverse weather conditions. It is also unknown what level of the imbalance between demand and capacity causes congestion and by how much the travel time is affected. Bad weather also impacts roadway mobility by increasing travel time delays, reducing traffic volumes and speeds, increasing the speed variance (i.e., a measure of speed uniformity), and decreasing roadway capacity (i.e., the maximum rate at which vehicles can travel).

Moreover, traffic congestion that results from bad weather may alter the destinations of travelers or cause them to altogether forego their trips. However, most existing studies focus on changes in the level of service such as the drop in speed, the decrease in the volume of traffic, and the occurrence of weather-related accidents. Although information on trips by origin and destination is required for analyzing transportation planning in urban areas, few studies have examined the relationship between weather conditions and travel patterns. Hassan & Barker (1988) reported a reduction of

three percent in traffic on rainy weekdays and four percent on weekends, while Brodsky & Hakkert (1988) revealed an increase in traffic volumes on rainy days as a result of a shift by travelers in the mode of transport to automobiles.
This paper investigates the characteristics of travel patterns on Korean expressways in rainy days of the year 2006. We compare the normal travel patterns with those of rainy days by traffic volume, and by the travel distance for each type of vehicle. It is known that traffic volume is dependent upon trip purposes. Compulsory trips for commuting and working are not greatly influenced by weather, but non-compulsory trips such as recreational and shopping trips are influenced. This paper focuses on the impacts of weather on travel characteristics in rainy days. Results show that, as expected, the traffic volume and travel distance decrease in rainy days; the findings also reveal differing travel patterns for weekdays as compared with weekends.
This paper has been organized as follows. In the next section, travel characteristics in rainy days are given, and more detailed comparisons are presented. In section 3, a mathematical model has been developed to formulate a relation between rainfall and traffic volume, and finally, in section 4, conclusions are drawn.

2. IMPACT OF WEATHER CONDITIONS ON TRAVEL CHARACTERISTICS

In this paper, we focus on some issues that are derived from extant research on the topic. They are itemized below.

1. Do traffic volumes increase or decrease, when broken down by the mode of travel?
2. Is there any difference in travel distances on rainy days compared with other days?
3. With reference to travel patterns, are weekdays different from weekends?
4. Do traffic volumes increase or decrease with the level of precipitation?

We use rainfall data for the year 2006 that encompass 76 observations made daily around the country of Korea; these are shown in Figure 1. Table 1 presents the numbers of rainy days and the associated numbers of observations that detected rainfall. To estimate the number of days without rain, we assume that the whole country experiences rain on any given day if the number of observations that detect rainfall on that day exceeds 55. Table 2 displays the dates for each month when it rained around the country, i.e., when at least 55 observations of rainfall were recorded. The table confirms that June and July were the wettest months of the year, accounting for 30 percent of all precipitation in 2006.

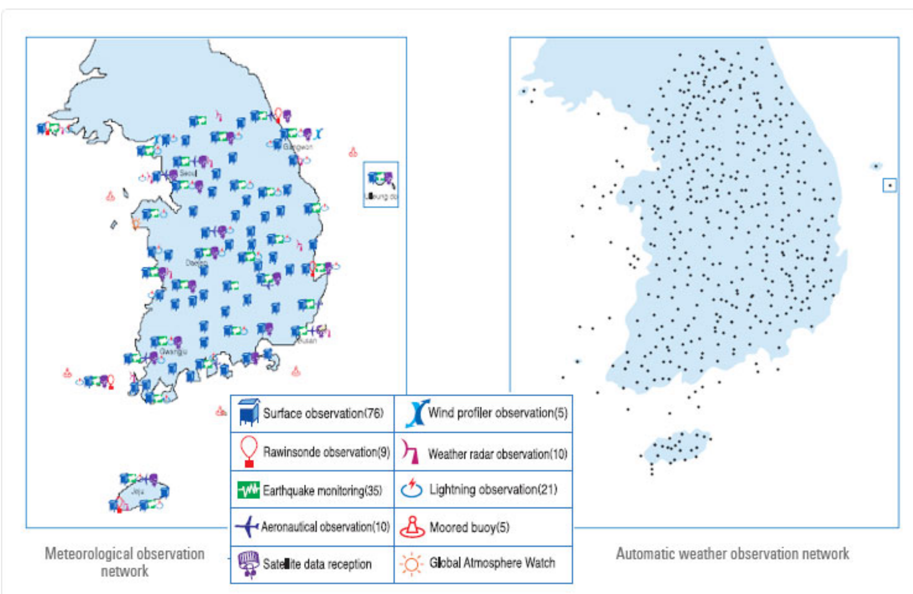

Figure 1. Observations of rainfall over Korea

Table 1. Rainy days in 2006

Number of observations	74 observations	65 observations	60 observations	55 observations
Rainy days	15	40	52	65

Table 2. Rainy days detected at more than 55 observations in 2006

Month	Rainfall of the 55 station	Number of rainy days
January	13, 31	2
February	1,7,14,15,28	5
March	1,16	2
April	1,2,4,9,10,11,19	7
May	6,10,19,22,27	5
June	8,10,14,15,21,25,26,29,30	9
July	1,4,5,9,10,11,12,15,16,17,18,19,20,21,25,26,28	17
August	25,27,30	3
September	5,6,16,17,18	5
October	22,23	2
November	5,6,27,28	4
December	7,8,9,17	4

In this paper, traffic volumes are analyzed using the data of toll collection systems (TCS) on freeways in 2006. TCS classifies vehicles on expressways into five types: Type 1 (auto, small vehicle); Type 2 (medium car, medium truck); Type 3 (heavy vehicle, bus, heavy passenger car); Type 4 (heavy truck); and Type 5 (specialized vehicle).

Comparison of traffic between rainy and dry days

Table 3 presents, for each month, the average daily traffic, the traffic on rainy days, the traffic on dry days, and the difference between them. As one would expect, the average traffic on rainy days is less than that on dry days, especially in July and August. For seven of the 12 months, the average daily traffic is greater than the overall average, while for the remaining five months, the average daily traffic is less than the overall average. The traffic on rainy days is always lower than the average daily traffic for the whole year. Table 4 displays more details for each type of vehicle.

For a clearer comparison of traffic volumes between rainy days and dry days, we performed the statistical ANOVA test shown in Table 5, which confirms a significant difference between the two volumes.

Table 3. Average daily traffic, rainy-day traffic, and dry-day traffic

Month	Average daily traffic (veh/day)	Rainy-day Traffic (veh/day)	Dry-day traffic (veh/day)	Difference between rainy days and dry days (%)
January	1,918,296	1,890,006	1,920,247	1.60%
February	1,897,590	1,810,286	1,916,569	5.90%
March	1,946,959	1,943,023	1,959,412	0.80%
April	2,000,490	1,930,853	2,021,684	4.70%
May	2,056,032	1,967,084	2,073,138	5.40%

June	1,991,480	1,940,132	2,023,823	4.30%
July	1,913,623	1,812,529	2,036,381	12.40%
August	2,133,116	1,938,158	2,154,005	11.10%
September	2,115,836	2,011,312	2,136,740	6.20%
October	2,139,246	1,971,400	2,150,821	9.10%
November	2,128,376	1,997,000	2,148,587	7.60%
December	2,036,301	2,019,724	2,038,757	0.90%

Table 4. Comparison of travel patterns across types of vehicle

		Summation	Type 1	Type 2	Type 3	Type 4	Type 5
Dry day (A)	Traffic (vehicle)	2,049,457	1,675,656	133,252	75,203	32,010	67,389
	Total travel distance (km)	116,914,879	93,705,669	7,889,772	6,118,750	1,976,999	4,400,714
	Average travel distance (km)	57.0	55.9	59.2	81.4	61.8	65.3
	Proportion(%)	100	81.8	6.5	3.7	1.6	3.3
Rainy day (B)	Traffic (vehicle)	1,902,361	1,553,260	124,525	73,142	28,859	60,908
	Total travel distance (km)	106,713,670	84,976,184	7,380,328	5,973,076	1,823,288	4,002,277
	Average travel distance (km)	56.1	54.7	59.3	81.7	63.2	65.7
	Proportion(%)	100	81.6	6.5	3.8	1.5	3.2
comparison	Difference of traffic (A-B)	-147,096	-122,396	-8,727	-2,061	-3,151	-6,481
	%	-7.2	-7.3	-6.5	-2.7	-9.8	-9.6
	Difference of total travel distance (km)	-10,201,210	-8,729,485	-509,444	-145,674	-153,710	-398,438
	%	-8.7	-9.3	-6.5	-2.4	-7.8	-9.1
	Difference in average travel distance (km)	-1.0	-1.2	0.1	0.3	1.4	0.4
	%	-1.7	-2.2	0.1	0.4	2.3	0.6

Table 5. Statistical test (ANOVA)

Factor	Df	SS	MS	F	P-value
Treatment	1	1.05E+12	1.05E+12	28.6	1.57E-07
Residual error	361	1.33E+13	3.68E+10		
Total	362	1.44E+13			

Travel patterns of rainy days

There are two types of trip, compulsory and non-compulsory. The compulsory trips are for commuting and working, while non-compulsory trips are for recreation, shopping, and family events. Weather conditions may be expected to more significantly impact upon non-compulsory trips.

Data analysis shows that the amount of traffics on rainy days decreased by 7.2% as a whole, but there is

no difference between vehicle types. This phenomenon is not consistent with the expectation that Type-1 travel will dramatically decrease on the grounds that it comprises trips for recreation and touring; rather, it implies that Type-1 vehicles have been used for compulsory trips, i.e., those pertaining to commuting and work.
The total trip length also decreased by 8.7 percent, which is larger than the decrease in traffic. Among vehicle types, Type 1 exhibited the greatest decrease, which can be explained through concerns of safety with small vehicles on rainy days. However, as clarified in Figures 2 and 3, for the other types, the total trip length was almost the same for rainy days as for dry days.

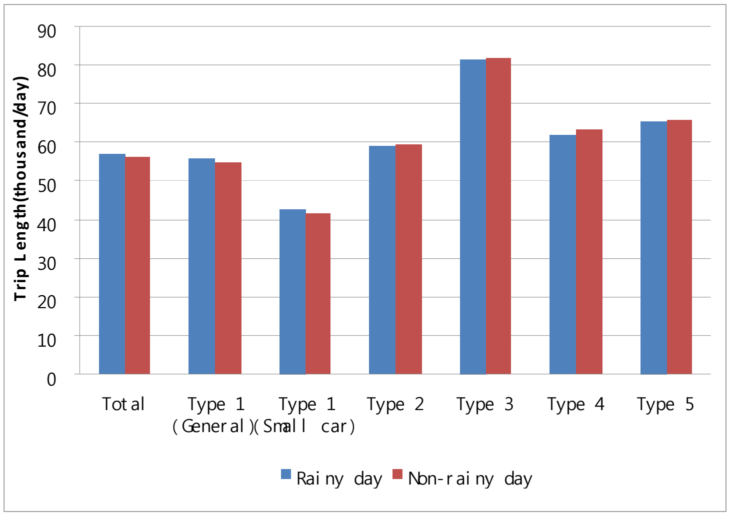

Figure 2. Change in the total trip length for each type of vehicle

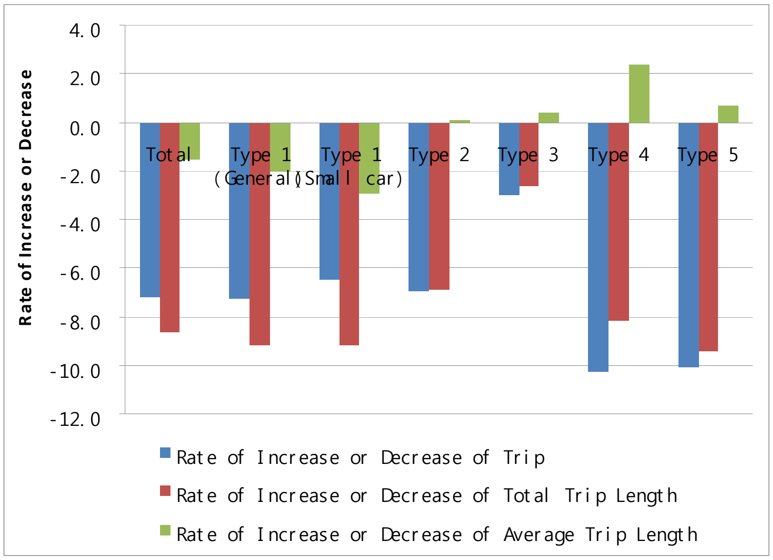

Figure 3. Changes in travel patterns

Travel patterns of weekdays and weekends

The weekday data for Type-1 vehicles on rainy days show that the total trip length is more reduced in comparison with the volume of traffic. However, the total trip length did not decrease for heavy vehicles such as trucks and interregional, passenger buses as these vehicles make compulsory trips.
In contrast, Figure 4 shows that on weekends, the trip lengths and traffic volumes of all vehicles, except

those of Type-1, considerably decreased when compared with those on weekdays. This phenomenon is expected because weekend trips are non-compulsory; so, travelers are free to change their final destinations and cancel trips by themselves on rainy weekends. Table 6 and Table 7 describe the travel patterns on both weekdays and weekends.

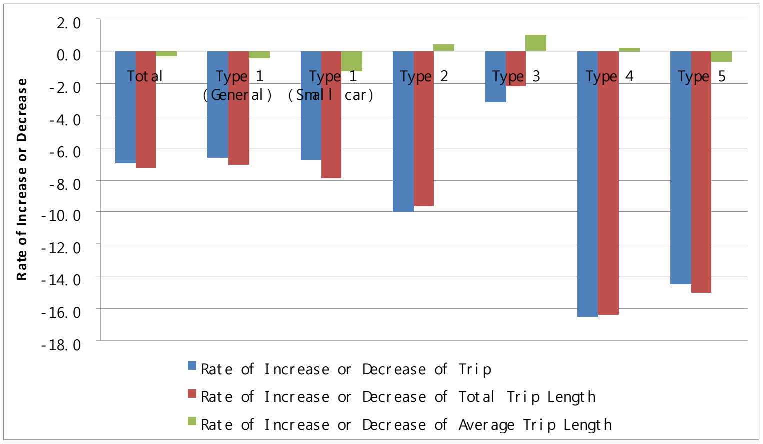

Figure 4. Changes in travel patterns on weekend rainy-days

Table 6. Travel patterns on weekdays

	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 5**
Traffic in rainy day (vehicles)(A)	1,495,317	143,123	75,078	33,989	71,150
Traffic in dry day (vehicles) (B)	1,605,838	156,749	78,363	38,029	80,143
Difference(A-B)	- 110,521	-13,626	- 3,285	- 4,040	- 8,993
%	-6.88	-8.69	-4.19	-10.62	-11.22
Total travel distance on rainy day(km) (C)	77,397,129	8,441,307	5,998,812	2,169,144	4,700,931
Total travel distance on dry day (km) (km) (D)	84,633,410	9,230,129	6,224,057	2,355,924	5,238,987
Difference(C-D)(km)	- 7,236,280	-788,822	- 225,245	- 186,779	- 538,055
%	- 8.55	- 8.55	- 3.62	- 7.93	- 10.27
Average travel distance in rainy day(km) (E)	52	59	80	64	66
Average travel distance in dry day (F) (km)	53	59	79	62	65
Difference (E-F) (km)	- 0.94	0.09	0.48	1.87	0.70
%	- 1.79	0.16	0.60	3.02	1.07

Table 7. Travel patterns on weekends

	Type 1	Type 2	Type 3	Type 4	Type 5
Traffic in rainy day (vehicles)(A)	1,716,862	72,012	67,677	14,374	31,989
Traffic in dry day (vehicles) (B)	1,844,373	77,817	68,074	17,774	37,622
Difference(A-B)	- 127,511	- 5,806	- 396	- 3,400	- 5,633
%	- 6.91	- 7.46	- 0.58	- 19.13	- 14.97
Total travel distance in rainy day(km) (C)	106,375,868	4,384,620	5,900,411	846,754	2,018,395
Total travel distance in dry day(km) (km) (D)	115,347,281	4,730,358	5,908,028	1,076,450	2,446,862
Difference (C-D) (km)	- 8,971,413	- 345,738	- 7,617	- 229,696	- 428,467
%	- 7.78	- 7.31	- 0.13	- 21.34	- 17.51
Average travel distance in rainy day(km) (E)	62	61	87	59	63
Average travel distance in dry day (F) (km)	63	61	87	61	65
Difference (E-F) (km)	- 1	0	0	- 2	- 2
%	- 0.93	0.16	0.46	- 2.73	- 2.99

3. ESTIMATION OF A REGRESSION MODEL FOR RAINFALL AND TRAFFIC

In this section, we estimate the parameters of the regression model that expresses the relation between rainfall and traffic on rainy days. Monthly traffic volumes are adjusted by monthly variance factors. Figures 5 and 6 display the frequency of precipitation and traffic volumes.

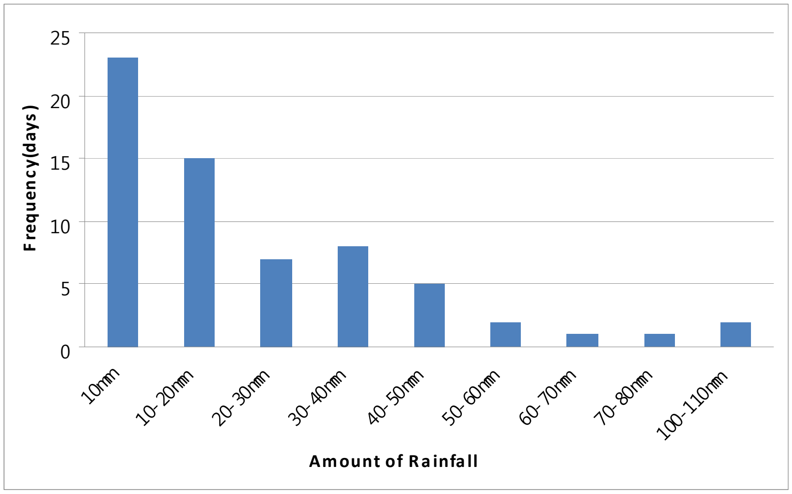

Figure 5. Frequency of precipitation

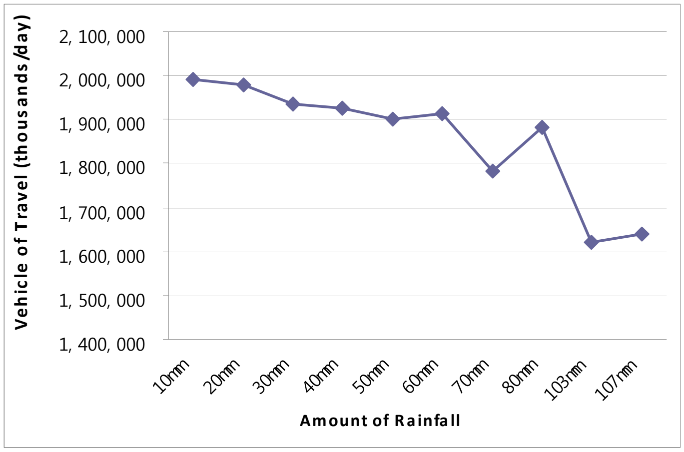

Figure 6. Traffic volumes by level of precipitation

Figure 7 plots precipitation against traffic volume on weekends, and indicates no strong relationship between the two. The same is true for weekdays (Figure 8), although the relationship is somewhat stronger compared with that for weekends.
When we eliminate those days from the analysis that experienced less than 10mm of precipitation, we obtain a more reliable model, which is shown in Figure 9. The regression equation is given below and the R^2 , which is the explanatory power of the regression model, is 0.519.

$$y = (2E + 6) + 9.643\ln(x)$$

Where, y is the traffic volume (thousands of vehicles/day) and x is the precipitation (mm).

In addition, each type of vehicle also exhibits similar travel patterns, e.g., traffic volumes decrease with increasing precipitation.

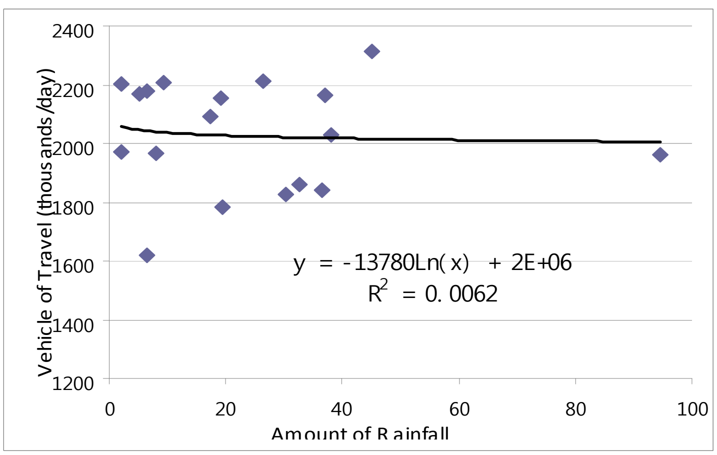

Figure 7. Regression model (weekends)

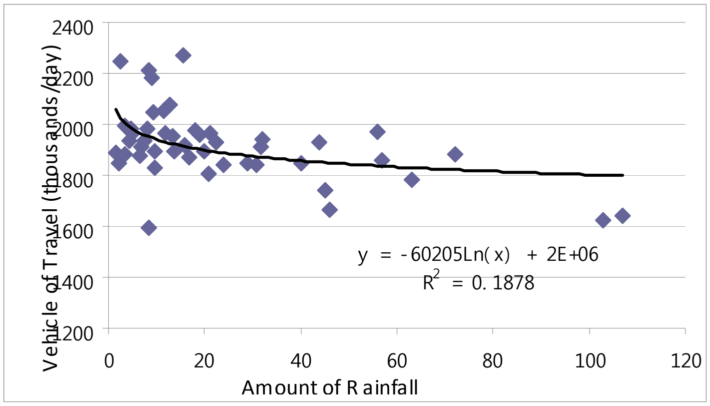

Figure 8. Regression model (weekdays)

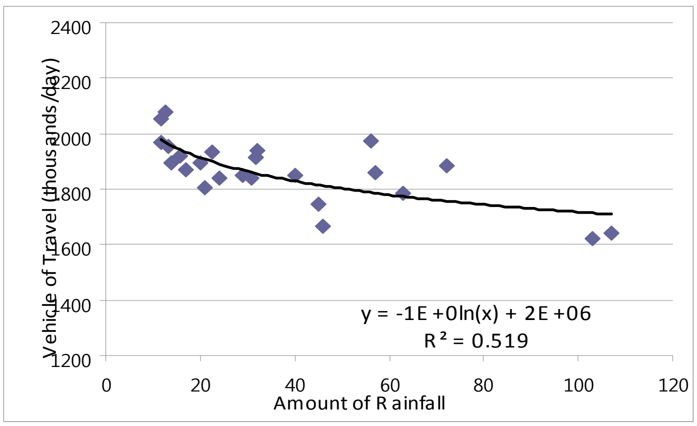

Figure 9. Regression model (eliminating those days with less than 10mm precipitation)

4. CONCLUSION

Korea has clear four seasons that make for diverse weather conditions that, in turn, greatly impact upon driver behavior on expressways. This paper investigates the impact of rain on travel patterns in expressways in terms of traffic volume, weekdays vs. weekends, and the amount of rainfall. The results can be summarized as follows.

1. *Traffic volumes on rainy days*: Traffic volumes decrease as a whole on rainy days. There is no significant difference among the various types of vehicle, including Type-1 vehicles, which suggests that such vehicles, which include automobiles, are used for compulsory trips pertaining to commuting and work.
2. *Travel distance on rainy days*: On rainy days, the total travel distance decreases relatively more than the traffic volume, particularly for Type-1 vehicles, given concerns about road safety.
3. *Differences between weekends and weekdays*: The traffic volume and travel distance decrease more on weekends compared to weekdays because trips on weekends are for non-compulsory purposes.
4. *Travel patterns and the amount of precipitation*: On those days when there is over 30mm of precipitation, traffic volumes decrease more significantly.

This study is merely the first phase in research that is needed with regard to the management of expressways under adverse weather conditions. Because of the impact of weather conditions on the travel patterns of drivers, the relationship between rainfall and traffic patterns is expected to play an important role in transportation planning and the operation of Korean expressways.

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